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Life Cycle Inventory of Medium Density Fibreboard

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Abstract

Goal, Scope and Background. Wood is the most important renewable material. The management of wood appears to be a key action to optimise the use of resources and to reduce the environmental impact associated with mankind's activities. Wood-based products must be analysed considering the two-fold nature of wood, commonly used as a renewable material or regenerative fuel. Relevant, up-to-date environmental data are needed to allow the analysis of wood-based products. The main focus of this study is to provide comprehensive data of one key wood board industry such as the Medium Density Fibreboard (MDF). Moreover, the influence of factors with strong geographical dependence, such as the electricity profile and final transport of the product, is analysed.
In this work, International Organization for Standardization standards (ISO 14040-43) and Ecoindicator 99 methodology have been considered to quantify the potential environmental impact associated to the system under study. Three factories, considered representative of the 'state of art', were selected to study the process in detail: two Spanish factories and a Chilean one, with a process production of around 150,000 m^3 per year. The system boundaries included all the activities taking place into the factory as well as the activities linked to the production of the main chemicals used in the process, energy inputs and transport. All the data related to the inputs and outputs of the process were obtained by on-site measurements during a one-year period. A sensitive analysis was carried out taking into account the influence of the final transport of the product and the dependence on the electricity generation profile.

Life Cycle Inventory Analysis. LCI methodology has been used for the quantification of the impacts of the MDF manufacture. The process chain can be subdivided in three main subsystems: wood preparation, board shaping and board finishing. The final transport of the product was studied as a different subsystem, considering scenarios from local to transoceanic distribution and three scenarios of electricity generation profile were assessed. The system was characterised with Ecoindicator 99 methodology (hierarchic version) in order to identify the 'hot spots'. Damage to Human Health, Ecosystem Quality and Resources are mainly produced by the subsystem of Wood Preparation (91.1%, 94.8% and 94.1%, respectively). The contribution of the subsystem of Board Finishing is considerably lower, but also significant, standing for the 5.8% of the damage to HH and 5.5% of the damage to Resources.

Conclusions. With the final aim of creating a database of wood board manufacture, this work was focused in the identification and characterisation of one of the most important wood-based products: Medium Density Fibreboard. Special attention has been paid in the inventory analysis stage of the MDF industry. The results of the sensitive analysis showed a significant influence of both the final transport of the product and the electricity generation profile. Thus, the location of MDF process is of paramount importance, as both aspects have considerable site-dependence.

Recommendations and Perspectives. Research continues to be conducted to identify the environmental burdens associated to the materials of extended use. In this sense, future work can be focused on the comparison of different materials for specific applications.

Keywords: Chipboard manufacture; life cycle assessment (LCA); life cycle inventory (LCI); medium density fibreboard (MDF); wood-based panels

Introduction

Wood is the most important, renewable material and regenerative fuel [1]. As a material, wood is one of the resources most widely used for its remarkable properties, i.e. high strength, low specific weight, good insulation properties, availability, etc. [2]. Due to a broad of potential applications, it is often in competition with other materials such as concrete, steel or plastics [3–4]. However, this material is not only used as raw material for manufacture of different tools. Its use as biomass fuel accounts for 14% of the worldwide energy consumption and demand continues to increase for the use of biomass for energy, partly driven by the targets to fulfil national commitments under the Kyoto Protocol [5–6].

The wood panels market in the Economic Commission for Europe region fared better than other primary sectors, as measured by the largest increases in consumption coupled with higher prices [5]. The main breakdown of wood-based panels is presented in **Fig. 1**. The main panels in Europe are particleboard, which figures for approximately 65% of the total panel production and Medium Density Fibreboard (MDF), which accounts for 20%. The MDF industry has continued its solid growth for the last ten years in the 19 countries of the European Free Trade Association (EFTA), with an MDF consumption of 8.7 million cubic metres reported in 2003, as well as 2.3 million cubic metres for other Europe regions (22 countries) [5]. MDF consumption in the United States has also been increasing during last years, rising to 4.3 million cubic metres in 2004 [5].

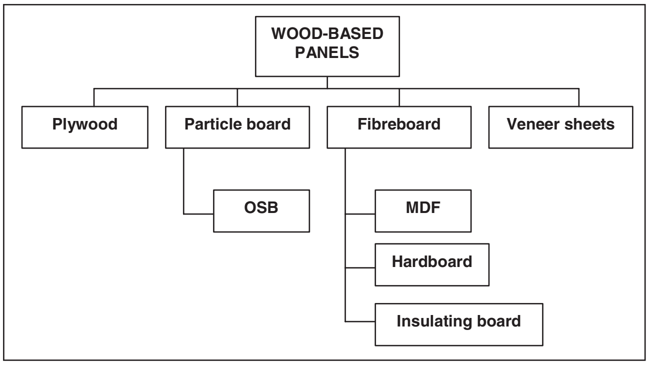

Fig. 1: Breakdown of major wood-based panels. OSB: Oriented Strand Board; MDF: Medium Density Fibreboard

Wood management is a key action to optimise the use of resources and to reduce the environmental impact associated with mankind activities. In this sense, Life Cycle Assessment (LCA) methodology has proved to be a valuable tool to evidence and analyse the environmental impacts of products and services systems that need to be part of decision- making process towards sustainability [7]. However, it is not possible to determine the specific causes of the greatest environmental burdens in the life cycle until all the stages have been evaluated and the quality of data used has been fully verified. Wood-based products must be analysed considering the twofold nature of wood, commonly used as renewable material or regenerative fuel. As a first priority, allocation should be avoided by system expansion, thus adding additional functions to the functional unit [8–9].

Since LCA application began to be significant during the 1990s, efforts have been made to make progress in this area specifically in relation to forest operations [10–12]. So far, no comprehensive Life Cycle Inventory (LCI) for wood board manufacture, the most common items of wood-based materials, was available in the literature [13]. In previous work, we analysed the particleboard industry in detail [13]. The main focus of this study is to provide complete data of the other main wood board produced in the MDF industry.

1 Goal and Scope

1.1 Objectives

This work aims to generate comprehensive Life Cycle Inventory (LCI) for the manufacture of Medium Density Fibreboard (MDF). Besides, the influence of factors with strong site-dependence, such as the electricity profile and final transport of the product, is also analysed. As a first approach, several factories in different continents were analysed and minimal differences in the global inventory data were found (less than 5%). Three factories, considered representative of the 'state of art', were selected to study the process in detail: two Spanish factories and a Chilean one, with an approximate process production of 150,000 m^3 per year.

1.2 Functional unit

This unit provides a reference to which the inputs and outputs are referred [14]. The functional unit chosen was 1 m^3 of finished MDF for a better comparison with other materials. The material density is approximately 615 kg/m^3 with 8% water content.

1.3 Description of the system under study

The Composite Panel Association defines MDF as a dry-formed panel product manufactured from lignocellulosic fibres combined with a synthetic resin or other suitable binder [15]. The mechanical refining process is carried out at high temperature. A synthetic resin binder, typically urea formaldehyde, is added to provide strength properties and paraffin wax is supplemented for protection against accidental water spillage.

The density of MDF panels oscillates from 496 to 801 kilograms per cubic metre (kg/m^3). In contrast to particleboard, MDF has more uniform density throughout the board and has smooth, tight edges that can be machined. It can be finished to a smooth surface and grain printed, avoiding veneers and laminates. Thick MDF panels (1.27 to 1.91 cm) are used as core material in furniture panels. MDF panels thinner than 1.27 cm are typically used for siding.

The general steps used to produce MDF include mechanical pulping of wood chips to fibres (refining), drying, blending fibres with resin and sometimes wax, forming the resined material into a mat, and hot pressing. The process chain can be subdivided in three main subsystems: wood preparation, board shaping and board finishing. **Fig. 2** presents a process flow diagram for a typical MDF plant.

Subsystem of Wood Preparation. The main sources of biomass are normally wood chips. Wood chips are typically delivered by truck or rail from offsite locations such as sawmills, plywood plants, furniture manufacturing facilities, satellite chip mills, and whole tree chipping operations sawmill. The chips are washed to remove dirt. Clean chips are softened in a steam-pressurized digester and then transported into a pressurized refiner chamber. In the refiner chamber, single or double revolving disks are used to pulp the softened chips into fibres suitable for the manufacture of the board (defibrator unit). The sequence of the drying and blending operations depends on the method by which resins and other additives are blended with the fibres. Most facilities inject resin formulations into a blowline system; if a blowline system is used, the fibres are first blended with resin, wax and other additives in a blowline, which is a channel that discharges the resined fibres to the dryer. After drying, the fibres are removed from the gas stream by a fibre recovery cyclone (fibre sifter) and then conveyed to a dry fibre storage bin.

Subsystem of Board Shaping. Air conveys the resined fibres from the dry storage bin to the forming machine, where they are disposed on a continuously moving screen system (mat former unit). The continuously formed mat must be prepressed before being loaded into the hot press (precompressor unit). The press applies heat and pressure to trigger the resin and bond the fibres into a solid panel. The mat may be pressed in a continuous hot press, or the precompressed mat may be cut by a flying cut-off saw into individual mats that are then loaded into a multi-opening, batch-type hot press. Steam or hot oil heating of the press plates is common in domestic MDF plants.

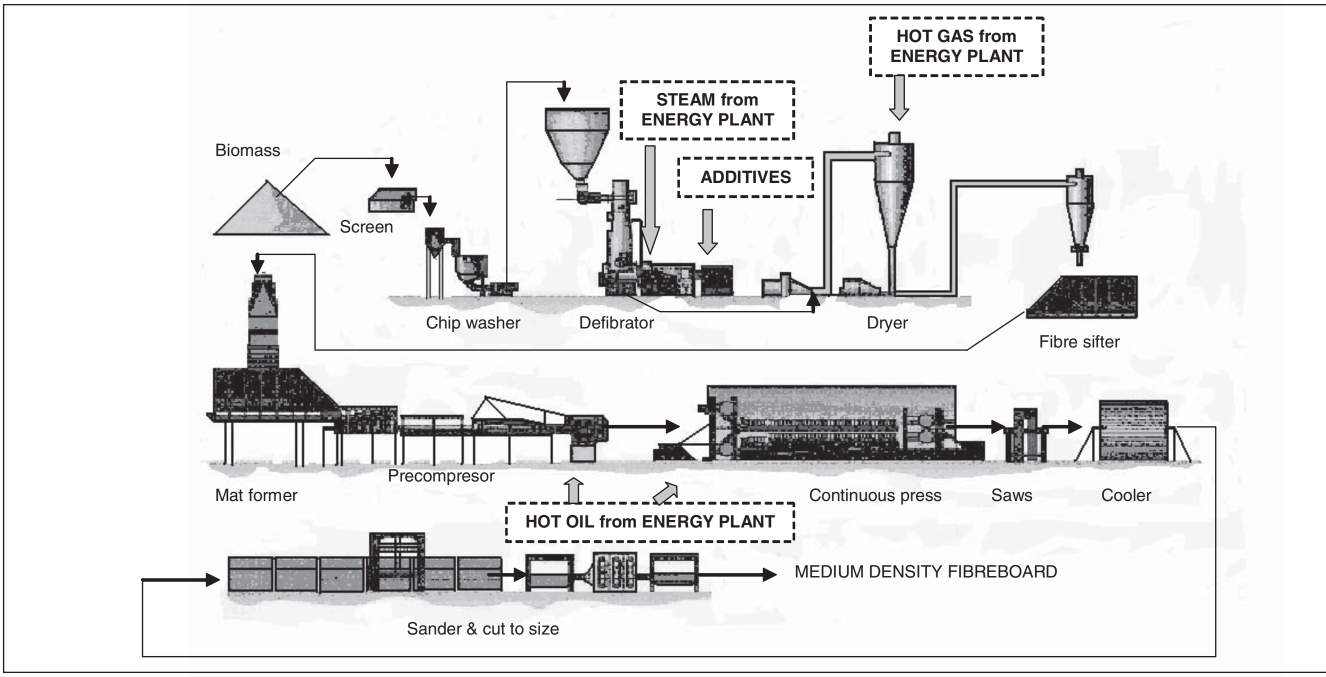

Fig. 2: Flow sheet of MDF manufacture

Subsystem of Board Finishing. After pressing, the boards are cooled, sanded, trimmed, and sawed to final size. The boards may also be painted or laminated. Finally, the finished product is packaged for delivery.

Ancillary activities

- **Chemicals.** The production of UF and transport to the factory were considered in the subsystem of wood preparation.
- **Transport.** Chips and sawdust are delivered by truck from nearby locations. The distribution of the product finished is not included in the system boundaries because of its strong geographical dependence, and was further analysed as a different subsystem.
- **Energy.** Energy consumption in the subsystems of wood preparation, board shaping and board finishing was included in their respective inventory data.
- **Auxiliary activities.** Auxiliary activities in the factories were also computed, taking into account the employees' water consumption and different wastes generated: municipal waste, metals, oil, paper & paperboard and toner units.

1.4 Data quality

High quality data are essential to make a reliable evaluation. All the data related to the inputs and outputs of the process were obtained by on-site measurements during a one-year period. Minimal differences (less than 5%) in the global inventory data were found in all factories, due to a well-developed technology. The subsystem linked to urea-formaldehyde (UF) resin production was inventoried from bibliographic data from the PRé Consultants Database [16].

The assignment of the environmental loads associated to the different sources of electricity was made according to the IDEMAT 2001 database [16]. Inventory data of electricity from cogeneration were taken from ETH-ESU 96 database [17]. In the case of transport, the assignment of the environmental loads was made according to BUWAL 250 database [18].

In wood-based products LCA, the infrastructures of the production facilities are usually not taken into account as the differences are negligible compared to the overall environmental impacts of the product life cycle [8–9,19].

1.5 Sensitivity analysis

The geographical dependence of two factors was identified and further assessed: the electricity generation profile and the transport of the final product. The electricity profile is of major importance as it broadly affects the environmental impacts assigned to energy-consuming steps. A sensitivity analysis was carried out in order to evaluate the dependence on the electricity generation profile. Three scenarios were considered: Scenario A corresponds to an electricity generation profile including 30% of nuclear energy, 15% of hydroelectric energy and electricity from coal, gas and oil (35%, 10% and 10%, respectively); Scenario B stands for the electricity generation profile with no nuclear energy and 50% of hydroelectric energy, 13% from gas and 37% from coal; Scenario C represents the electricity supply coming from a cogeneration unit.

The relative importance of the final transport of MDF manufactured was analysed in detail, based on the delivery routes reported by the companies. Diverse scenarios from local to transoceanic distribution were assessed (see Table 5).

Table 1: Wood Preparation inventory for 1 m³ of MDF processing

Inputs from Technosphere			
Materials (kg)		**Energy (MJ)**	
Biomass		Electricity for machine	889.5
Green chips (56% water content)	460	Energy from biomass	
Dried chips (11% water content)	530	Hot gas to drier	1,602.73
Sawdust (57% water content)	90	Steam to defibrator	1,534.03
Total	**1,080**	**Total**	**3,136.76**
Additives		**Transport (t km)**	
UF-Resin	44.44	4–5 ton truck	27.22
Urea solution	1.43	6–8 ton truck	8.76
Paraffin	2.34	12–14 ton truck	263.52
Paraffin emulsion	0.88		
Ammonium sulphate	0.24		
Total	**49.33**		
Outputs			
To Technosphere		**To Environment**	
Materials to board shaping (kg)		**Emissions to air (kg)**	
Resinated fibres to forming machine	713.48	Filterable matter	1.74
		Condensed matter	0.42
		Nitrogen oxides	0.71
		Carbon dioxide	215.66
		Carbon monoxide	0.62
		Formaldehyde	0.022

2 Life Cycle Inventory Analysis

Chips and sawdust coming from sawmill are wood by-products that can be used as raw materials and fuel. For the purpose of this work, they were considered waste from other activities. Besides, when comparing previous activities with MDF manufacture, it seems that an allocation of the environmental burdens coming from previous activities to the wood waste would not turn into a significant contribution. For instance, Berg and Lindholm (2005) reported in a recent work an energy use of 150–200 MJ, from seeding production to delivery to the industrial site, to produce 1 m³ of timber in Sweden; this value has minor importance when comparing with MDF manufacture consumption (**Tables 1–3**). Thus, the wood waste had no environmental burden allocation from previous processes and only their transport and further processing were computed (see Table 1).

All the data related to the consumptions of the subsystems of wood preparation, board shaping and board finishing were obtained from the companies. The differences in the global inventory data were minimal so we decided to report aver-

Table 2: Board Shaping inventory for 1 m³ of MDF processing

Inputs from Technosphere			
Materials (kg)		**Energy (MJ)**	
Resinated fibres to forming machine	713.48	Electricity for machine	25.541
		Energy from biomass	
		Hot oil to press	517.43
Outputs			
To Technosphere		**To Environment**	
Materials (kg)		**Emmissions to air (kg)**	
Fibreboards shaped	705.44	Filterable matter	0.020
Fibreboards rejected	8.04	Condensed matter	0.022
		Formaldehyde	0.023

Table 3: Board Finishing inventory for 1 m³ of MDF processing

Inputs from Technosphere			
Materials (kg)		**Energy (MJ)**	
Fibreboard shaped	705.44	Electricity for machine	355.79
Outputs to Technosphere			
Products and Coproducts (kg)			
Board finished (8% water content)	615		
Waste to drier (kg)			
Sand down dust	53.67		
Waste from sawdust	36.76		

age values. The primary emissions sources at MDF manufacture are fibre dryers and press vents. Values reported in Table 1 summarized average values of emissions from dryer stage reported by the factories. Emissions from board hot presses are related to the type and amount of resin used to bind the wood fibres together. When the press opens, vapours with formaldehyde content are released (see Table 2). For the subsystem of Board Shaping, the emissions of formaldehyde from press were estimated based on the emission factors reported by US-EPA (2002).

The other main emission source is the boiler, which can be fed with several fuels. The energy required for the process was obtained from biomass in the three plants analysed. The thermal energy balance is described in **Fig. 3**. It is pointed out that the recycling of waste from the subsystem of board shaping and board finishing (fibreboard rejected, sand down dust and waste from sawdust) was considered and this internal recycling was an input to the energy plant (see Fig. 3). Thus, no allocation procedure was necessary, since the residual wood was used for the generation of heat on site (included within the system under analysis) [20]. It is noteworthy that the combustion of wood under a sustainable wood production may be CO_2-neutral, but not CO_2-free. Energy generation avoids natural oxidation (respiration) of biomass by emitting the same amount of CO_2; therefore, in a 50-years scenario, the carbon cycle might be closed [21]. As a first approach, the volume of CO_2 released by wood burning was considered equal to the CO_2 up-take necessary for photosynthesis.

Auxiliary activities in the factories were also computed and data referred to the production of 1 m³ of MDF. Main data corresponded to the employees' water consumption (56.9 L) and different wastes generated: 1.51 kg of municipal waste, 209 g of metals, 2 g of waste oil, 97 g of paper & paperboard and 0.4 toner units.

Final transport of MDF manufactured was analysed in detail based on the delivery routes reported by the companies. In order to identify the relative importance of this aspect, final transport was studied as a different subsystem. This point will be discussed in Section 4.2.

3 Discussion

In this work, the impact assessment was performed with the Ecoindicator 99 methodology, which reflects the state of art in LCA [22]. Only the phases of classification and characterisation were studied, as it is the least subjective approach.

3.1 Classification and characterisation

Human Health (HH), Ecosystem Quality (EQ) and Resources (R) are the three conditions considered. Modelling and estimation of an environmental indicator for each category or issue are carried out in this stage. Damages to HH are expressed in Disability Adjusted Life Years (DALY). Damages to EQ are expressed as Potentially Disappeared Fraction (PDF) and Potentially Affected Fraction (PAF) of species due to an environmental impact. The PDF and PAF values are then multiplied by the area size and the time period to obtain the damage. Damages to R are expressed as the surplus energy for the future mining of the resources.

The characterisation step analyses the contribution of the different subsystems to the impact categories, essential to detect the 'hot spots'. The results for the characterisation step and damage assessment are shown in **Table 4**. The subsystem of wood preparation exhibits the highest contributions to all the categories analysed. Board finishing subsystems show a significant contribution to Carcinogens, Ecotoxicity and Minerals categories, which accounts for 5.8% of the damage to HH and 5.5% of the damage to R. The main contribution to these categories is related to en-

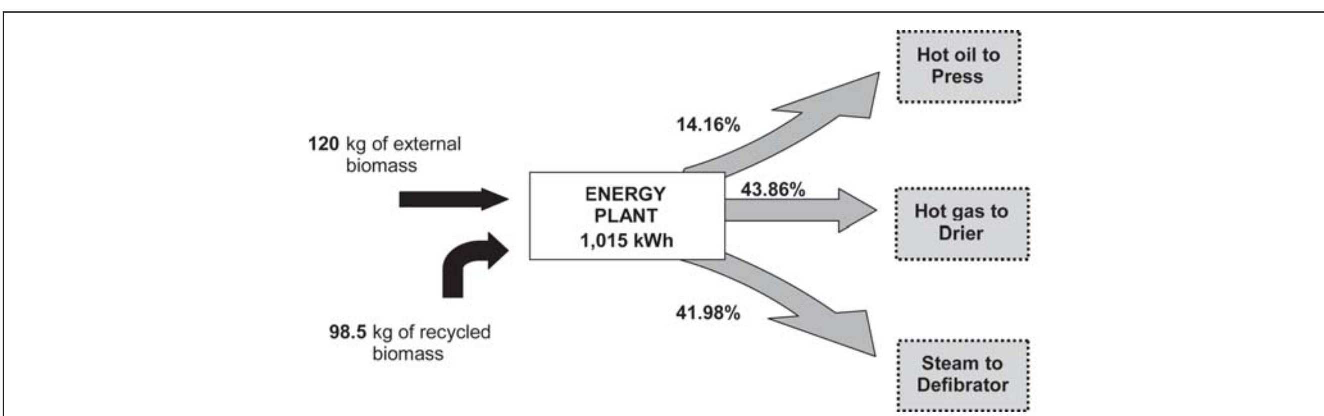

Fig. 3: Thermal energy balance for 1 m³ of MDF processing

Table 4: Characterisation and Damage Assessment of MDF manufacture/Eco-indicator 99 related to the functional unit. Units: DALY: Disability Adjusted Life Years. PDF: Potentially Disappeared Fraction. PAF: Potentially Affected Fraction. MJ surplus: surplus energy for the future mining of the resources

Characterisation step				
Category	**Unit**	**Wood preparation**	**Board shaping**	**Board finishing**
Human Health				
Carcinogens	DALY·10^6	22.6	0.6	8.3
Respiratory organics	DALY·10^7	5.5	0.3	0.1
Respiratory inorganics	DALY·10^5	37.0	0.9	1.6
Climate Change	DALY·10^5	12.0	0.7	0.9
Ozone layer	DALY·10^9	57.8	0.1	1.1
Ecosystem Quality				
Ecotoxicity	PAF·m²yr	11.11	0.2	2.4
Acidification/Eutrophication	PDF·m²yr·10	125.0	0.5	6.9
Land use	PDF·m²yr·10	605.0	2.1	28.7
Resources				
Minerals	MJ surplus·10^2	16.3	0.5	6.4
Fossil fuels	MJ surplus	318.0	1.3	18.6
Damage Assessment				
Human health	DALY·10^5	51.4	1.7	3.3
Ecosystem quality	PDF·m²yr	74.1	0.3	3.8
Resources	MJ surplus	318.0	1.3	18.7

ergy consumption. Thus, wood preparation has the largest impacts on the mentioned categories as this subsystem is the most dependent on the use of electricity (with a contribution of 91.1% to damage to HH and 94.1 to damage to R). On the other hand, damage to EQ is mainly caused by the UF used in the subsystem of wood preparation. Therefore, the contribution of this subsystem stands for 94.8% of the process.

3.2 Sensitivity analysis of electricity profile generation

The dependence on the electricity generation profile was analysed considering three scenarios:

- Scenario A, with an energy production model including energy from coal, nuclear, gas, oil and hydroelectric.
- Scenario B, characterised by the absence of nuclear energy and mainly supported by hydroelectric energy, gas and coal.
- Scenario C, with an energy production from a cogeneration unit using gas as energy source.

Fig. 4 shows the comparative characterisation results of MDF manufacture with different electricity profiles. As the results infer, the electricity profile affecting energy-consuming steps was of major importance. When considering the possibility of a cogeneration unit (MDF-C), the damage to HH and EQ were minimized because of the low emissions of this technology, but the highest damage to R was registered (being natural gas as the sole energy source). When comparing the scenarios A with B, the presence of a higher contribution of hydroelectric energy (MDF-B) appeared to be more favourable when considering the damage to HH and damage to EQ. However, the major dependence on fossil fuels of this profile led to a stronger damage to R (an increase of 32.8% in relation to MDF-A). The variability observed points out the influence of the geographical location of MDF manufacture, because the process is clearly dependent on the electricity profile characteristic of each region.

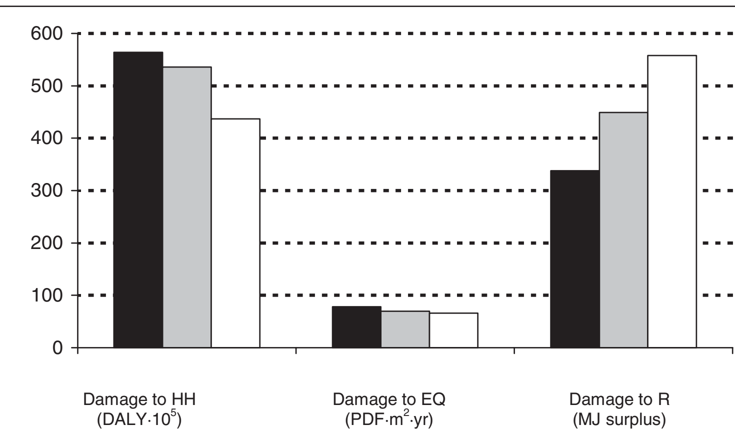

Fig. 4: Comparative damage assessment of electricity generation profile scenarios. (■) MDF-A; (■) MDF-B; (□) MDF-C

Table 5: Models of transport for MDF distribution

Model	Distance (km)	Type of transportation	Description
MDF	0	None	MDF manufacture, without considering the distribution of the product.
MDF+TA	200	Truck	MDF manufacture considering a local distribution of the product by a 28-ton truck, an average distance of 200 km.
MDF+TB	725	Truck	MDF manufacture considering a national distribution of the product by a 28-ton truck, an average distance of 725 km.
MDF+TC	2,000	Truck	MDF manufacture considering an European distribution of the product by a 28-ton truck, an average distance of 2,000 km.
MDF+TD	30 10,000	Truck Ship	MDF manufacture considering a transoceanic distribution of the product, an average distance of 30 km to the port by a 28-ton truck and 10,000 km by ship.

3.3 Sensitivity analysis of transport

A noteworthy characteristic of MDF factories all over the world is the distribution routes of the final product. A sensitivity analysis was carried out in order to identify the relative importance of this aspect. Final transport of MDF manufactured was analysed in detail, based on the delivery routes reported by the companies, considering diverse scenarios from local to transoceanic distribution (**Table 5**).

The variation on the damage assessments results with the model of transport considered is shown in **Fig. 5**. The results obtained exhibit a major influence of the distance of transport in relation to the environmental impact of the process. The rise in the distance of delivery increases all the modelled damage, especially damage to resources. It is remarkable that there is an important reduction in the environmental burdens when the transport is carried out by ship. The transoceanic distribution considered (10,000 km on average) produces lower environmental impact than a distribution of the product by truck covering an average distance of 725 km.

4 Conclusions

With the final aim of creating a database of wood board manufacture, this work focused on the identification and characterisation of one of the most important wood-based products: Medium Density Fibreboard. Special attention has been paid in the inventory analysis stage of the MDF industry. The results of the detailed quantification of the process can serve as a basis to evaluate the use of the product, recycling and disposal in such a way that the environmental burdens are minimized and reduced to levels that are competitive and may even outperform potential substitutes.

The subsystem of wood preparation has the largest impacts related to damage to HH and damage to R, as this subsystem is the most dependent on the use of electricity. Damage to EQ is mainly caused by the UF used as synthetic resin binder.

The results of the sensitive analysis showed a significant influence of both the final transport of the product and the electricity generation profile. The geographical location of MDF process must be considered comprehensively.

5 Perspectives

Research continues to be conducted to identify the environmental burdens associated to the materials of extended use. In this sense, future work can be focused on the comparison of different materials for specific applications.

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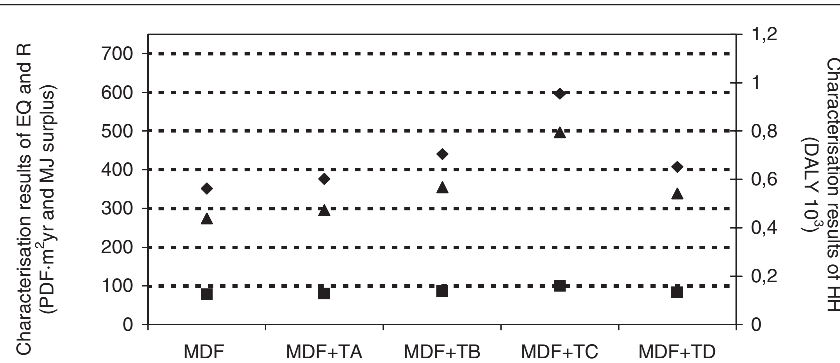

Fig. 5: Comparative damage assessment of transport scenarios. (◆) **HH**: Human Health; (■) **EQ**: Ecosystem Quality; (▲) **R**: Resources. Units: DALY: Disability Adjusted Life Years. PDF: Potentially Disappeared Fraction. MJ surplus: surplus energy for the future mining of the resources

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Life Cycle Assessment of Wood Floor Coverings

A Representative Study for the German Flooring Industry

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Abstract

Goal, Scope and Background. The goal of the study is a life cycle assessment according to ISO 14040–14043 for wood floor coverings (solid parquet, multilayer parquet, solid floor board and wood blocks). The representative study covers approximately 70% of all wood flooring production in Germany. The comparison of the floor coverings among each other was not the aim. Instead the study provides basic data for all wood floor coverings for a possible comparison with other floor coverings later on. The main focus was a hot spot analysis to help the involved industry partners to improve their environmental performance, and to use the results for marketing purposes.

Inventory Analysis. The study covers the whole life cycle from forest management, sawmilling, manufacturing, laying and surface finishing through to refurbishment and end-of-life. The end-of-life scenario is the thermal utilisation of the floor coverings. The energy gained in the end-of-life scenario is accounted for by system expansion (avoided burden approach).

Impact Assessment. In the Impact Assessment the following categories were considered: global warming (GWP), acidification (AP), eutrophication (EP), ozone depletion (ODP) and photo-oxidant formation (POCP) following the CML baseline 2000 method. Furthermore the use of primary energy is presented.
The low emissions of greenhouse gases during the life cycle can lead to a negative contribution to the global warming potential if more emissions are avoided through the substitution process than are emitted during the life cycle of the product. Mainly energy consumption and the use of solvents influence the environmental impacts of the systems under analysis. The most relevant unit processes for the issue of energy consumption are 'production' and for photo-oxidant formation 'laying', 'surface finishing' and 'refurbishment'. These are therefore the unit processes with the greatest potential for improvement.

Normalisation and Sensitivity Analysis. The normalisation results show that the photo-oxidant formation potential is most significant in comparison to the other impact categories. Improvement options and the choice of the functional unit have been further explored in a sensitivity analysis.

Discussion and Conclusions. The most important opportunities for improvements are located in the unit processes laying, surface finishing and refurbishment. The POCP result can be reduced significantly depending on the choice of glue and varnish at each of these stages. The results of the sensitivity analysis showed a potential for improvement in this category. No data for the production of an oil and wax finish was available. This option would be interesting to consider at in a further study. The time aspect of storing CO_2 for a period of time is not considered in this paper, but will be addressed in a forthcoming paper (Nebel and Cowell 2003).

Keywords: Case studies; floor coverings; German flooring industry; parquet; wood